NOAA Technical Report NESDIS 101

EVOLUTION OF THE WEATHER SATELLITE PROGRAM IN THE U.S. DEPARTMENT OF COMMERCE - A BRIEF OUTLINE

Washington, D.C.
July 2001

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

NOAA TECHNICAL REPORTS

National Environmental Satellite, Data, and Information Service

The National Environmental Satellite, Data, and Information Service (NESDIS) manages the Nation's civil Earth-observing satellite systems, as well as global national data bases for meteorology, oceanography, geophysics, and solar-terrestrial sciences. From these sources, it develops and disseminates environmental data and information products critical to the protection of life and property, national defense, the national economy, energy development and distribution, global food supplies, and the development of natural resources.

Publication in the NOAA Technical Report series does not preclude later publication in scientific journals in expanded or modified form. The NESDIS series of NOAA Technical Reports is a continuation of the former NESS and EDIS series of NOAA Technical Reports and the NESC and EDS series of Environmental Science Services Administration (ESSA) Technical Reports.

A limited number of copies are available by contacting Jessica Pejsa, NOAA/NESDIS, E/RA2, 5200 Auth Road, Room 601, Camp Springs, Maryland 20746. Copies can also be ordered from the National Technical Information Service (NTIS), U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4650 (prices on request for paper copies or microfiche, please refer to PB number when ordering). A partial listing of more recent reports appear below:

NESDIS 63 A Systematic Satellite Approach for Estimating Central Pressures of Mid-Latitude Oceanic Storms. Frank J. Smigielski and H. Michael Mogil, December 1992.

NESDIS 64 Adjustment of TIROS Operational Vertical Sounder Data to a Vertical View. David Q.Wark, March 1993.

NESDIS 65 A Noise Level Analysis of Special Multiple-Spin VAS Data During Storm-fest. Donald W. Hillger, James F.W. Purdom and Debra A. Molenar, April 1993.

NESDIS 66 Catalogue of Heavy Rainfall Cases of Six Inches or more over the Continental U.S. during 1992. Charles Kadin, April 1993.

NESDIS 67 The Relationship between Water Vapor Plumes and Extreme Rainfall Events during the Summer Season. Wassila Thiao, Roderick A. Scofield and Jacob Robinson, May 1993.

NESDIS 68 AMSU-A Engineering Model Calibration. Tsan Mo, Michael P. Weinreb, Norman C. Grody and David Q. Wark, June 1993.

NESDIS 69 Nonlinearity Corrections for the Thermal Infrared Channels of the Advanced Very High Resolution Radiometer: Assessment and Recommendations. C.R. N. Rao (Editor), June 1993.

NESDIS 70 Degradation of the Visible and Near-Infrared Channels of the Advanced Very High Resolution Radiometer on the NOAA-9 Spacecraft: Assessment and Recommendations for Corrections. C.R. N. Rao (Editor), June 1993.

NESDIS 71 Spectral Radiance-Temperature Conversions for Measurements by AVHRR Thermal Channels 3,4,5. Paul A. Davis, August 1993.

NESDIS 72 Summary of the NOAA/NESDIS Workshop on Development of a Global Satellite/in Situ Environmental Database. Edited by K.P. Gallo and D.A. Hastings, August 1993.

NESDIS 73 Intercomparison of the Operational Calibration of GOES-7 and METEOSAT-3/4. W. Paul Menzel, Johannes Schmetz, Steve Nieman, Leo Van de Berg, Volker Gaertner, and Timothy J. Schmit, September 1993.

NESDIS 74 Dobson Data Re-Evaluation Handbook. R. D. Hudson and W.G. Planet (Eds), October 1993.

NESDIS 75 Detection and Analysis of Fog at Night Using GOES Multispectral. Gary P. Ellrod, February 1994.

NESDIS 76 Tovs Operational Sounding Upgrades: 1990-1992. A. Reale, M. Chalfant, R. Wagoner, T. Gardner and L. Casey, March 1994.

NOAA Technical Report NESDIS 101

EVOLUTION OF THE WEATHER SATELLITE PROGRAM IN THE U.S. DEPARTMENT OF COMMERCE - A BRIEF OUTLINE

P. Krishna Rao
Chief Scientist
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration
1335 East-West Highway
Silver Spring, MD 20910

Washington, DC
July 2001

U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

National Oceanic and Atmospheric Administration
Scott Gudes, Acting Under Secretary

National Environmental Satellite, Data, and Information Service
Gregory W. Withee, Assistant Administrator

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

Contents

Evolution of the Weather Satellite Program in the U.S. Department of Commerce - a brief outline

P. Krishna Rao

NOAA/NESDIS
1335 East-West Highway
Silver Spring, MD 20910

Abstract

The first U.S. Weather Satellite TIROS-1, was launched on April 1, 1960. It was a joint effort between the U.S. Weather Bureau (part of the U.S. Department of Commerce), National Aeronautics and Space Administration (NASA), the Department of Defense and the Industry. Details about the early origins of the satellite program in the U.S. Department of Commerce are sketchy and are not readily available in a simple document. Because of the author's association with the Weather Satellite Program in the U.S. Weather Bureau from its infancy for about forty years, an attempt is made to give a brief sketch about the evolution of the entire program in the early days. I had the opportunity of participating and observing it from close proximity, and am able to provide a brief history of the early days of the Weather Satellite Program. This article is not meant to be scientific in nature, but to provide some historic perspective.

Introduction

The Weather Satellite Program in the Department of Commerce started in the mid 1950's in the U.S. Weather Bureau (USWB). This write-up is an attempt to document the early history of the program and will not try to cover in-depth science and applications. The information will also be confined to the Department of Commerce, USWB activities with some references to the connections with the National Aeronautics and Space Administration (NASA) and private industry. The current U.S. Weather Satellite Program is now 40 years old and the documentation of the early history is fragmented and sketchy. Information derived from available memos, memory and some published articles has been used in preparing this manuscript.

The first reference to a weather satellite was by Greenfield and Kellogg of the RAND Corporation (2) in 1960. They published this paper when their original report issued in 1951 was de-classified and was permitted for release. They indicated the utility of a weather satellite for observing clouds over data-sparse oceanic areas and their use for weather analysis and forecasting. The first known paper proposing meteorological satellites was published by Harry Wexler, Director of Research in the USWB in 1954 (8). He also published another paper in 1957 (9) describing the potential contributions of satellites in meteorology. Wexler commissioned an artist in 1954 and asked him to produce a sketch of cloud cover over North America viewed from a satellite, if it was positioned 4000 miles over Texas. This sketch is reproduced in Figure 1. The types of clouds, cloud fields and the brightness are remarkable. In 1957 Singer published a paper proposing meteorological measurements from satellites (7). Later in June 1962, Singer became the first Director of the Meteorological Satellite Activities (MSA) in the USWB.

The need for weather observations from space was obvious. About 70 percent of the earth is covered by oceans and over these areas, weather observations were very few. Even over the continents, except over North America and Europe, the observations were limited. In order to observe the weather conditions around the globe on a continuous basis the satellites were found to be a suitable vehicle. Soon after World War II, the US Army launched V-2 rockets with cameras mounted in the nose and took pictures of the earth. The cameras were parachuted and recovered, and the images showed extensive cloud cover over the southern USA and also showed very interesting cloud patterns. These initial images demonstrated the need for satellites.

In March, 1958 the Chief of the USWB Dr. F. W. Reichelderfer established a special unit called the "Meteorological Satellite Research Unit" under the Director of Meteorological Research. He named Dr. S. Fritz as the head of the Meteorological Satellite Section. Annex 1 shows the memo and the proposed organizational structure. It has three Sections: Meteorological Satellite Instrument Development, Meteorological Satellite Research Unit, and Two Field Meteorological Satellite Telemetering Units. About five people were assigned to this unit from various parts of the USWB to begin the planning.

Six months later, in September 1958, the Director of Meteorological Research Dr. Wexler sent a memo to the USWB units indicating the formation of NASA Agency (not Administration at that time) and stating that the Weather Bureau would be designated as their meteorological agent in providing the meteorological instrumentation, data reduction and analysis of observations taken by satellites after the International Geophysical Year (IGY) series was finished. (See annex 2). The memo also describes in detail the types of data that were expected from the satellites and the research and development work that were needed. Imagine all these are being planned almost 2 years in advance of the first weather satellite launch and even without knowing the problems associated with the data sets. The list is comprehensive and will not be repeated here.

This small USWB group Meteorological Satellite Section moved to Suitland, Maryland and co-located their offices with the USWB offices in that area. The original group consisted of S. Fritz, D. S. Johnson, J .S. Winston, L .F. Hubert, D .Q. Wark, and D. Hillary. Within a few months several more people were recruited and added to the group. With the expansion of activities the name was changed to "Meteorological Satellite Laboratory" (MSL). This was the beginning of the major satellite program.

The first US Weather Satellite Television Infrared Observation Satellite (TIROS-1) was launched on April 1, 1960, from Cape Canaveral, Florida. Successful launch of TIROS-1 confirmed the idea that spectacular cloud photographs could be used immediately for weather analysis and forecasting. The satellite carried two Vidicon cameras - one a wide angle and the second one a narrow angle. The image of the earth and clouds was formed on the Vidicon tube (which is about 1-inch in diameter) and stayed for several seconds. During this period the image was scanned and signals was transmitted to the ground stations for reception and reconstruction of the image. As soon as one image was transmitted, the next sequence was started and thus a large segment of the globe was covered. The early satellites (TIROS 1-8, and TIROS 10) were shaped like a hat box and were allowed to spin along their vertical axis to keep them stable. Because of the nature of the polar orbit (50N - 50S) and the way the cameras were mounted on the spinning satellite, only a limited coverage of the globe was possible.

There were two primary ground stations to command and receive the satellite data. They were located at Ft. Monmouth, New Jersey, and Kaena Point, Hawaii. At the ground stations, pictures were displayed on kinescopes for immediate viewing and photographing. In the early stages of this program, NASA had the responsibility of planning, placing the satellite in orbit, tracking, acquiring, processing and analyzing the data. Assistance was provided by industry and other government agencies. The operational phase of the TIROS project was under NASA's computing center and the USWB's Meteorological Satellite Section (MSS). Meteorologists in the MSS were responsible for the analysis and interpretation of cloud cover data. Also, assistance for the weather analysis and interpretations was provided by Air Force Cambridge Research Center, Allied Research Associates, Air Weather Service, Navy Research Weather Facility, and Army Signal Corps. The U.S. Naval Photographic Interpretation Center developed and processed the photographs.

The Early Applications of TIROS Data

During the first 80 days of TIROS-1, approximately 2000 images of the earth and its cloud cover were obtained from both the narrow and wide angle television cameras. About 50 to 75 percent of the staff were involved in the operational use or research study of the TIROS cloud pictures. Considerable time was devoted in determining the satellite's orientation to obtain accurate location of cloud features in the pictures. Much of the staff at Suitland, Maryland was also concerned with the preparation of the prints of the pictures and their assembly, along with pertinent standard meteorological data for use in releases of picture data to the press, various scientific groups, and operational meteorological centers. The earliest meteorological results from TIROS were published in two articles one by Fritz and Wexler (1) and the other by Wexler and Fritz (10). By the end of April 1960, (almost 30 days after launch), a number of case studies of meteorological phenomena observed by TIROS were begun by a team of meteorologists in the Meteorological Satellite Section. These studies included several large-scale cyclonic vortices over the United States, the North Atlantic and the North Pacific; cloudiness in the tropical regions of the South Pacific; cellular arrangements of cumulus clouds over the Atlantic and Pacific

Oceans in temperate latitudes; cloud streets in the Caribbean, cloudiness associated with severe thunderstorms and tornadoes; ice in the Gulf of St. Lawrence; orographic clouds in various parts of the world; snow cover in mountain regions; and sun glitter on the ocean surface. Several technical reports were published by USWB and NASA in the following months.

The next step was to assemble a series of TIROS pictures and match them together for an entire orbit, or when the data were available, for a series of successive, adjacent orbits to observe interesting large-scale weather patterns and the associated cloud formations. One of the first constructed by Vince Oliver (4) is shown in (Figure 2). The top portion of the picture shows the unrectified mosaic of the image corrected for the varying viewing angles of the camera (rectified) with a superimposed surface weather analysis. The correlation between the cloud patterns and the surface weather analysis is excellent.

The TIROS pictures received at the ground stations were recorded on 35-mm film by a kinescope camera, either during a satellite readout or by playing back the data recorded on a magnetic tape. The film was processed immediately to make transparencies for projection and for prints. The geographic reference grids were overlaid on these pictures to determine the location where the pictures were taken. These overlay grids were generated by taking into account the position of the satellite, the time at which the picture was taken, the direction in which the camera was pointed, and other parameters connected with the satellite spin axis etc. Once the grids were overlaid on the pictures, cloud analyses (called nephanalyses) could be performed as shown in Figure (3). The analyses show the cloud types, amount and the extent of coverage. These maps were sent by facsimile to weather stations around the globe for immediate use. Within 48 hours of the TIROS-1 launch, the pictures and nephanalyses were made available to USWB meteorologists, US Air Weather Service and the US Naval Weather Service. The information was limited to areas where sun light was available and no night-time data were available. The introduction of infrared sensors on TIROS-2 and the follow-on satellites starting from November 1960, enabled us to obtain continuous day and night-time coverage.

The inclusion of infrared radiometers on TIROS added extra capabilities. For example, the measurements in the 8-12 μm channels provided an estimate of the cloud top temperatures, and thus one could infer the cloud top heights. One of the early studies by Rao and Winston (6), showed the cloud top temperatures and cloud heights determined over the United States using the TIROS-2 radiation data. The researchers compared the results with synoptic and aircraft data and found good agreement. It was also pointed out in this paper that the 8-12 μm window region is not clean and there is a considerable amount of absorption due to water vapor and ozone, and thus appropriate corrections needed to be applied.

Another interesting study was published by Winston and Rao (11) showing the temporal and spatial variations of the outgoing long-wave radiation derived from the TIROS-II radiometer. They used the observation from the 7-33 μm channel to estimate the total outgoing long-wave radiation at the top of the atmosphere. They showed the latitudinal distribution of the satellite derived data with available theoretical studies and found a reasonable agreement. They also showed a relationship between the outgoing long-wave radiation and the zonal kinetic energy at various latitudes.

Satellite pictures were also used to observe and map ice cover over the Gulf of St. Lawrence and the Great Lakes areas. These pictures were found to be very useful for navigation by observing the leads in the ice cover. Another important application was to monitor the extent of snow cover during winter and the melting of snow during spring. The snow cover information was found to be very useful for hydrological forecasting.

In the early days of the satellite data, the images had to be gridded before they could be used. Even with the grids, due to the uncertainties in orbit determination and the attitude of the satellites, location errors were noticed. Identification of landmarks in the images were very useful in aligning the grids and making the exact longitude-latitude coordinates. For the radiometer data, that was a different story. The analog signals from the radiometer (all the channels) were digitized and computer printouts were produced for each orbit. The printout contained the latitude/longitude of the scan spot and the corresponding digital values (counts) of each of the radiometer channel values. These radiometer channel values were later converted to either reflectance (albedo) or temperatures using look up tables. For each orbit a "thick stack" of computer printout was produced and technicians plotted these values (for each channel) on a base map. These maps were basically the same ones used by the USWB so that the satellite analysis could be overlaid on the weather analysis for the same period. A mapping program was developed during this period to ease the workload and use the radiation data as soon as it became available. The same grid scales used by the National Meteorological Center's Numerical Models was selected (1024x1024; 512x512; 256x256 per hemisphere scales) for mapping the satellite data. This decision was very useful and practical. All satellite information that was mapped could be overlayed on the weather charts (of the same scale) and compared. Analysis schemes used for the satellite data were also similar to the weather analysis schemes.

The first image from TIROS-1 was over the Gulf of St. Lawrence. It showed some clouds over New England and Canada and some ice over the Gulf of St. Lawrence. It was difficult to exactly locate the image, because the images were distorted (not rectified) and the latitude and longitude grids were not immediately available. The location of the satellite in space, and the attitude of the spin axis were needed to exactly locate the center of the picture. Also the north direction in the picture was needed to locate the cloud feature. When TIROS-1 was launched, it was assumed that attitude of the satellite in space relative to the fixed stars would stay the same throughout its lifetime. Analysis of the pictures showed that it was not true and extensive corrections had to be made while gridding the pictures. The causes for this deviation were found to be (1) the interaction between the magnetic field of the satellite and that of the earth and (2) the decrease of the gravitational force with height causes an object in space to tend to align itself with the vertical. As soon as these factors were known, they were incorporated in future satellite data processing. The satellite also carried a tape recorder to store the pictures when out of range of a ground data acquisition station. After collecting a few pictures from the early orbits of TIROS-1, Fritz and Wexler published a paper (1) describing the interpretation of the images and the respective synoptic situation. These images were sent by facsimile to regional USWB offices for immediate use. A series of satellite images gathered over large areas were assembled as a mosaic to view the cloud systems associated with various synoptic situations (Fig 2). These pictures were also analyzed to exhibit the types of clouds (low, medium, and high level) and the amounts and a nephanalysis was produced. These composite products were provided to national and international meteorological offices. These images and nephanalysis were found to be very useful. They were available only for the daylight portion of the globe because the Vidicon cameras were sensitive to the visible part of the spectrum only.

In order to observe both day and nighttime cloud cover, radiometers were installed on the next satellite, TIROS-2, and the follow-on satellites (TIROS 3, 4, 5 and 7). Three types of instruments were used: (a) a 5-channel scanning radiometer (b) 2-channel medium resolution radiometer, and (c) a 2-channel omni-directional radiometer. Of the three instruments the

5-channel one is the most important one. It consisted of the following:

(1) 59-6.7 μm to measure the atmospheric water vapor (because of the strong absorption in this spectral region)

(2) 8-12 μm atmospheric window to measure surface temperatures under cloud free conditions and cloud temperatures and heights and to obtain nighttime images.

(3) 0.2-5 μm to measure the albedo of the earth, clouds, etc. (reflectance)

(4) 7.0-30 μm to measure to the total outgoing longwave radiation at the top of the atmosphere

(5) 0.5-0.7 μm in the visible part of the spectrum to measure the reflected radiation and create images during the day time

The sensors were mounted in the satellite at an angle of 45 degrees to the spin axis of the satellite. The scan was produced by the spin of the satellite. The movement of the satellite provided the coverage along the track. Because of the spin of the satellite the sensors looked alternatively at space and at the earth. The field of view of the radiometer was approximately 30 miles.

The medium resolution radiometer flown on TIROS 2, 3 and 4 consisted of two detectors each mounted in a separate cone; the field of view was a few hundred miles. The field of view approximately coincided with the field of view of the wide angle cameras so that comparison could be made between the cloud cover and the radiation measurements. One detector was coated white to measure only the long wave radiation above 4 μm. The second detector was coated black; it measured both the short and long wave radiation (approximately 0.2 to 40 μm). During the nighttime both these detectors were to provide the same amount of emitted radiation since no reflected radiation was present. This was one of the ways to check the performance of the two detectors.

The third set of radiometers on TIROS 2, 3, and 4 were developed by Prof. Verner Suomi of the University of Wisconsin. It consisted of two sets of hemispheres; two black and two white. The black and white pairs were mounted on opposite sides of the satellite with mirror backings so that the satellite structure was not in the field of view. The effective field of view was approximately 1000 miles in diameter. This instrument measured the total reflected solar radiation and the emitted earth-atmosphere long wave radiation and was primarily used to study the radiation balance of the earth-atmosphere system.

All these radiometer measurements were stored in the tape recorder on board the satellite and transmitted to the ground station after each orbit. The data were processed after the reception at the ground station. The data from medium resolution and the wide field of view radiometers were found to be noisy and marginally useful. The scanning radiometer was found to be very useful for various meteorological applications. With the experience gained from these early measurements, various changes were made to the follow-on instruments, which will be discussed later.

Early Evolution of the Organization

A reference has already been made regarding the establishment of the Meteorological Satellite Section in 1958 in the USWB. In 1960, the name was changed to the Meteorological Satellite Laboratory (MSL), and in 1962 it became the Meteorological Satellite Activities (MSA) with S. Fred Singer as the first Director and David S. Johnson as the Deputy Director. The following year it became the National Weather Satellite Center and with the departure of Singer, Dave Johnson became the Director. With the formation of the National Oceanic and Atmospheric Administration and the accompanying reorganization, the Environmental Data and Information Service was merged with NESS and the organization was renamed the National Environmental Satellite, Data, and Information Service (NESDIS). With Dave Johnson's retirement, Dr. John McElroy became the Assistant Administrator and in 1986, he resigned. Dr. William Bishop was the Acting Assistant Administrator and Mr. Tom Pyke became the Assistant Administrator of NESDIS. He continued till 1992. After Mr. Pyke, Mr. Winokur became the Assistant Administrator for NESDIS until 1999, when Mr. Greg Withee became the Assistant Administrator of NESDIS.

Annex 1 shows the initial organization of the MSS in 1958. It had three units: (1) Meteorological Satellite Instrument Development, (2) Meteorological Satellite Research Unit, and (3) Two field Meteorological Satellite Telemeter Units. Total proposed staff was approximately 30 people! Most of them were recruited from within the USWB. Within 6 months of the establishment of the MSS, Harry Wexler provided an extensive outline (Annex-2) of the Satellite Meteorology work that needed to be pursued in the organization. He identified that the following types of data would become available within the near future.

1. Cloud cover data
2. Heat budget of the earth
3. Nocturnal cloud cover using infrared atmospheric water vapor "window"
4. "Temperature" as inferred from water vapor and CO_2 emission in the infrared (Soundings)
5. Ozone distribution
6. Spectrum of solar radiation

Wexler identified the steps required to utilize the data. All these were described in 1958, almost 2 years before the launch of the first weather satellite. He was a visionary!

The Meteorological Satellite Section became the MSL and by June 30, 1960, the staff consisted of about 40. Contracts for construction of a new wing in Suitland was let by GSA and the building was expected to be ready by mid 1961 (current wing O in FB4, Suitland, MD). The following units were part of the MSL

1. Instrumentation and Observation Unit
2. Synoptic Meteorology Unit
3. Computation Unit
4. General Aviation Unit
5. Physical Meteorology Unit

The research activities pursed by these groups are summarized in Annex-5, a first progress report prepared by Dave Johnson. The extent of planning for future instruments (Sounders) and the processing and analysis of data are described in this document.

The severe limitation of the early TIROS satellites for meteorological applications was realized very early in the program. The inclined orbit and the spin stabilization provided coverage of the earth between 65N and 65S latitudes. The cameras were pointing toward the earth one-fourth to one-third of each orbit. Also, the weight, space, and power of TIROS limited the number and types of sensors that could be mounted. Realizing the limitations, NASA launched a new satellite program called NIMBUS.

NASA's NIMBUS Program:

The NIMBUS was primarily designed by Dr. Rudolph Stampfl and his associates at NASA's Goddard Space Flight Center (GSFC) in 1959. The objectives of the design were 1) a near-polar orbit to permit observation of the entire earth (from pole to pole), 2) earth-stabilization so that the cameras and other sensors could always point toward the earth 3) a retrograde (east to west) orbit inclined about 80° to the equator so that the satellite crosses the equator at local noon (north bound) and local mid night (south bound) on every orbit, 4) an altitude of 1000 km (600 nautical miles) to avoid the Van Allen radiation belt and to provide enough overlapping coverage at the equator, and, 5) a modular construction to allow for easy exchange of sensors and communication modules. Originally the plan was for NASA GSFC to integrate and test the spacecraft. However, in 1961, several separate contracts were awarded for the various subsystems; and a contract was awarded to the General Electric Missile and Space Vehicle Department, Valley Forge, Pennsylvania, for the final integration. NIMBUS was totally a new system and more complicated than the TIROS. The program was designed to be a test-bed for testing new sensors and systems for future operational systems. The program was in trouble right from the beginning, and the deadlines could not be met in completing the systems for integration and testing.

The first NIMBUS carried the Advanced Vidicon Camera Subsystem (AVCS) to provide global coverage. It also carried the Automatic Picture Transmission (APT) subsystem to provide pictures of local cloud patterns directly to suitably equipped weather stations as the satellite passed over them. The AVCS and APT cameras provided images only during the daylight portion of the orbit. The NIMBUS carried an improved version of a radiometer called the High Resolution Infrared Radiometer (HRIR) to observe in the 8-12 μm window region, and in the region 3.4 to 4.2 μm (a clear window). The NIMBUS also carried a radiometer, similar to the TIROS radiometer. This was called the Medium Resolution Infrared Radiometer (MRIR) and again the window channel was changed to 10-11 μm so that the absorption due to ozone and water vapor could be eliminated (much cleaner window region of the IR spectrum).

The NIMBUS 1 was launched from the Pacific Missile Range on August 28, 1964 on a Thor Agena rocket. The main NASA Command and Data Acquisition (CDA) station was near Fairbanks, Alaska. Also a station near Rossman, North Carolina was used occasionally to acquire data. As mentioned earlier, the NIMBUS program was a NASA experimental program to test new instruments and concepts before they could be incorporated into the operational weather satellites for which USWB was responsible. Due to the extreme delays encountered in the early stages of the NIMBUS program, the USWB had to back out of the program and find alternate solutions to keep the TIROS program operational.

Weather Satellites Become Operational

In June 1962, Dr. S. Fred Singer was appointed the Director of the Meteorological Satellite Activities by the Chief of the USWB. Annex 5 (which is a memo from Singer to his staff) describes the policies and the organization of the unit. It describes in detail the "operational" responsibility of the weather satellite bestowed on the USWB by the US Congress in PL 87-332. Singer defines the responsibilities thrust on the organization and the tasks assigned to various groups and identifies the management structure. Eighteen months after the launch of the first satellite TIROS-1, a fully operational entity was identified and established. One of the major decisions Singer made was to have the USWB to pull out of the NASA's NIMBUS program because of the delays it encountered. This was a controversional decision at that time even within the USWB and the working relationship with NASA was strained.

By mid 1962, 6 TIROS satellites were launched; they demonstrated the utility of the cloud observations and the radiometer measurements. To reflect the operational nature, the name of the organization was changed to National Weather Satellite Center and Dr. Singer became the first Director. In the early days of the satellite program, it was realized that in addition to the cloud information, the temperature and moisture distribution with height in the atmosphere is essential for the forecasters. The numerical modeling of the atmosphere was gaining momentum at this time and observations over the vast oceanic regions and other data void regions of the world were needed to fill the gaps in these models. A prototype instrument called the Satellite Infra Red Spectrometer (SIRS) was under development within the Meteorological Satellite Laboratory under the direction of David Wark and Don Hillary. The first sounder was on the NIMBUS Satellite launched in 1969. NASA was also developing another sounder at the same time to launch on a NIMBUS satellite; it was called the Vertical Temperature Profiling Radiometer (VTPR). Observations from the SIRS instrument were used to derive the soundings (vertical distribution of temperature and to a limited extent the moisture) over the oceanic regions. The satellite derived soundings were compared to the nearby radiosonde observations; the differences were about 2°K in the lower atmosphere and about 3°K in the upper atmosphere. However, these observations were found to be useful for numerical weather forecast models, particularly over the oceanic regions, where the radiosonde data are not available. The SIRS instrument worked for a short period and so the VTPR data from the NIMBUS Satellite were obtained by NOAA (from NASA) to utilize in the NWP models. Because of the high spectral resolution of the VTPR data, it was found to be superior to the SIRS data. Immediate plans were made to improve the VTRP instrument to an operational status and move it to the NOAA polar satellites. The first operational sounder was launched on NOAA-2 in 1972. The sounders continued on all Polar Orbiting satellites from that period.

Another interesting episode that took place in the early 1960's when the TIROS satellites were being considered for operations should be mentioned. Some senior people in NASA were not in favor of labeling the TIROS program as an operational program; they wanted to consider it as a research program and opposed immediate operational use of TIROS data. NASA refused the USWB use of the TIROS data for operational weather analysis for several weeks after the launch of TIROS. NASA also felt NIMBUS should also be fully tested before declaring any instruments to be ready for operations. The two main groups that wanted the satellite data to be operational were the USWB and DOD Weather Services.

To settle some of the differences (research vs. operations) with regard to the TIROS satellite operations, in October 1960, an interagency group consisting of NASA, USWB, DOD, and FAA established a panel called the Panel on Operational Meteorological Satellites (POMS) under the auspices of the National Coordinating Committee for Aviation Meteorology (NACCAM). NACCAM was chaired by the chief of the USWB. The first chairman of POMS was Mr. E.M. Cartwright of NASA; and Dr. Tepper of NASA served as the secretary. This group developed the report "Plan for a National Meteorological Satellite System (5). This report was completed in April 1961, and submitted to the Congress.

Some of the highlights of the report are interesting. It said that the operational meteorological satellite system should:

- Satisfy the meteorological requirements of all the users
- Phase into operation at the earliest date
- Capitalize on the continuing research and development program
- Serve first the United States, but where possible also serve international needs.

The report was also favorably reviewed by several government committees, and on May 25, 1961, President Kennedy's address to the Congress on "Urgent National Needs" (3) requested funding for these activities (approximately $53 million dollars) to be given to the USWB.

- All these details are also mentioned in the memo from S.F. Singer mentioned earlier (Annex 5). These were the turbulent times; the NIMBUS program was facing technical problems and the launch dates were slipping. The TIROS satellites were to become operational and the data to be made available to the users on a routine basis.

Because of the delay in NIMBUS, new instruments could not be tested in time on NIMBUS to incorporate them on operational weather satellites. At that time S. F. Singer, the Director of the NWSC, made the decision to provide funds to build a couple more TIROS satellites to maintain continuity of operations, rather than continue to fund NASA to develop NIMBUS. This decision created some friction between NASA and USWB with regard to the satellite activities. Within a few months after this episode, S.F. Singer left USWB and Dave Johnson became the Director. He worked through POMS to reestablish the connection between the research and operational satellites.

Some of the important transitions that took place from research satellites to operational satellites are:

- The POLAR satellites were changed from cartwheel to three-axis stabilized mode
- The High Resolution Infrared Radiometer (HRIR) on NIMBUS was modified and improved and became the Very High Resolution Radiometer (VHRR)
- The High Resolution Infrared Sounder (HIRS) on NIMBUS was modified and became the Vertical Temperature Profile Radiometer (VTPR)

These three instruments were first flown on the NOAA-2 Satellite that was launched on October 15, 1972. It is important to note that the satellite configuration and the instruments were first tested in space as research experiments and then moved to operational satellites. With the discontinuation of the NIMBUS program by NASA, the concept of testing new instruments on research platforms also disappeared! Another major change to the instruments occurred in 1972, the VCS (Vidicon Cameras) were eliminated because it was possible to produce images of clouds etc. from the scanning radiometers (VHRR).

The three-axis stabilized box shape improved TIROS Operational Satellites (ITOS) started in 1970 and continued till 1978 with a change in the name to NOAA satellites to identify with the organization (ITOS-1 through NOAA-5) Thus, the third generation of POLAR operational weather satellites ended.

Fourth Generation of Polar Orbiting Satellites

The fourth generation of polar orbiting weather satellites started with TIROS-N in 1978. Major changes in the satellite bus were implemented. The satellites resembled those in the Defense Meteorological Satellite Program (DMSP). These satellites were also three-axis stabilized and carried the following instruments: AVHRR (4 channels), HIRS/2 (20 channel sounder), MSU (4 channels) SSU (3 channels), Data Collection System, and Electron and Proton Detector. The first satellite in this series, called the TIROS-N, was launched in October 1978 and was deactived in February, 1981. Two more satellites in this series, NOAA-6 and NOAA-7; continued to provide global coverage until July 1986.

An advanced version of TIROS-N series, known as ATN-series commenced with the NOAA-8 satellite in 1983. The first one in this series NOAA-8 carried an improved AVHRR, HIRS/2 sounder, MSU, SSU sounders, Data Collection Systems (DCS), Solar Environmental Mission (SEM) and the Search and Rescue Mission transponder. By this time in history several articles had been published about these satellites and various applications of data; and no attempt will be made to discuss either the systems applications, or impact of these data in operations. The major change was the introduction of the 5-channel AVHRR instrument to derive more accurate sea-surface temperatures. The TIROS-N series consisted of NOAA-8 through NOAA-14 satellites. The next generation of polar satellites known as NOAA-K series were launched in 1998. Some major improvements were made to the HIRS-2 sounder on NOAA-11. The improved version of the Solar Backscatter Ultra Violet (SBUV) instruments to measure Ozone distribution in the atmosphere which was originally flown on NASA's NIMBUS Satellites was included on NOAA-11 (SBUV/2) and continued on all the following NOAA satellites that were launched in the afternoon orbit. Again, no descriptions of the instruments, or the applications are provided here, since many articles are available in the open literature.

The fifth generation starting from NOAA-14 carry a new generation of sensors and are used for multiple applications. Since the purpose of this write-up is to document early stages of the polar satellite program in NOAA, the current and future satellite programs are not covered here.

Conclusions

A brief description about the beginnings of the weather satellite program that started in the USWB and continued in the successor agencies (ESSA, NOAA) has been provided. This effort is to document the development of the program and the early contributions of the pioneers who had the vision. I had the good fortune of working with those visionaries from the beginning of the program. Participation in discussions and debates about the selection of sensors, satellite orbits, and interpretation of data was thrilling and thought-provoking. That experience for me is priceless. I tried to capture the evolution of the program to the best of my knowledge, and I take full responsibility for any serious omissions.

Acknowledgments

My sincere thanks to Mr. Scott B. Gudes, the Acting Under Secretary for Oceans and Atmosphere and NOAA Administrator for taking me out for lunch and prodding me to document the beginnings of the weather satellite program in the U.S. Department of Commerce. He also reviewed the document and suggested some changes. I also thank Ms. Pat Viets for her review and editing of this article.

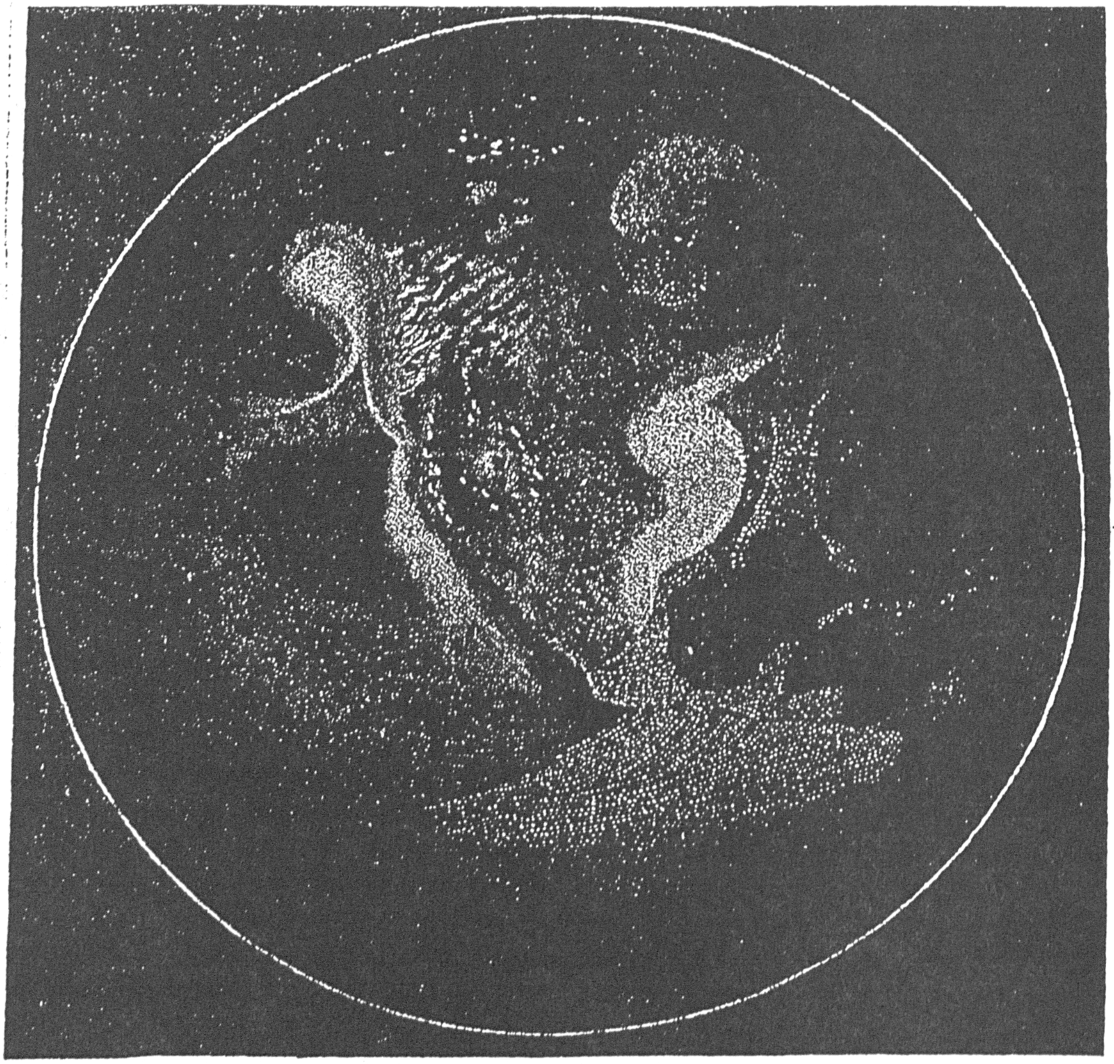


Fig. 1 Dr. Wexler's 1954 estimate of how a typical weather situation would appear from a satellite 4000 miles above Texas. (USWB)

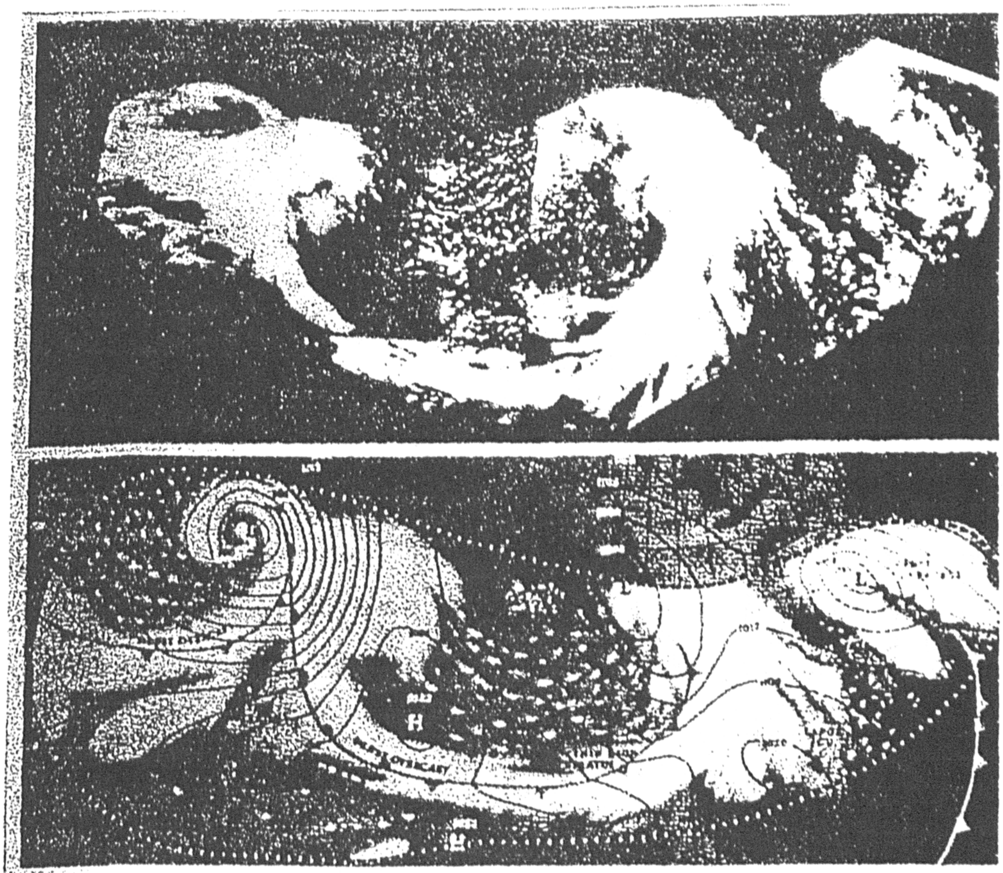


Fig. 2 Mosaic showing a family of storm systems exten from the mid-Pacific to the central United States. (USWB)

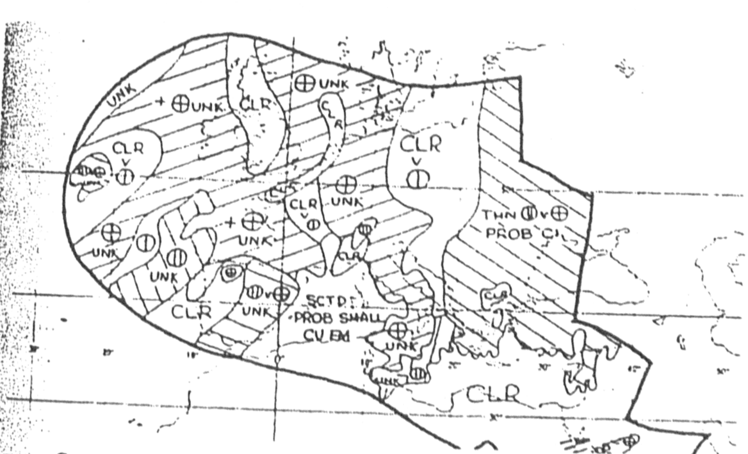


Fig. 3 The first operationally used TIROS nephanalysis (cloud analysis). (USAF)

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
Washington 25, D. C.

March 21, 1958

R-3

MEMORANDUM

TO: Heads of Offices and Project Leaders

FROM: Chief of Bureau

SUBJECT: Meteorological Satellite Research

On the reverse side of this memorandum we have sketched the organization for the Meteorological Satellite Section of the Office of Meteorological Research. Dr. S. Fritz has already begun work as one of the meteorologists of the Meteorological Satellite Research Unit to prepare for the data to be received from the meteorological experiments in connection with the U. S. International Geophysical Year Program. Additional personnel placement actions for this work are under consideration.

If questions are received from outside the Weather Bureau regarding the organization and work of the Meteorological Satellite Section, they should be referred to the Director of Meteorological Research.

F. W. Reichelderfer

F. W. Reichelderfer

OFFICE OF ME[illegible]OLOGICAL RESEARCH

METEOROLOGICAL SATELLITE SECTION

METEOROLOGICAL SATELLITE INSTRUMENT DEVELOPMENT

- 2 Meteorologists
- 2 Physicists
- 1 Electronic Engineer
- 3 Electronic Technicians
- 1 Laboratory Mechanic
- 1 Secretary

METEOROLOGICAL SATELLITE RESEARCH UNIT

- 3 Meteorologists
- 2 Mathematicians
- 8 Meteorological Technicians
- 1 Secretary

2 Field Meteorological Satellite Telemetering Units

HISTORICAL MILESTONES IN WEATHER SATELLITES

1.	Earliest WB enthusiasts: Harry Wexler, Sigmund Fritz.	
2.	1957 - IGY	: Two meteorological experiments on Vanguard (Suomi, Stroud).
3.	Summer, 1958	: WB started working with ARPA (DOD), which then was developing TIROS.
4.	September, 1958	: Meteorological Satellite Section formed within OMR to serve as NASA's meteorological arm, under NASA reimbursement. MSS grew into National Weather Satellite Center.
5.	April, 1959	: TIROS program transferred from DOD to NASA.
6.	April 1, 1960	: TIROS I launched. TV cameras only.
7.	November 23, 1960	: TIROS II launched. First IR radiometer.
8.	April, 1961	: NACCAM panel (POMS) recommends National Operational Meteorological Satellite System (NOMSS) based on Nimbus, with WB assuming responsibility to establish and operate system.
9.	May, 1961	: Pres. Kennedy's space message to Congress, resulting in first MSO appropriation to WB for FY 1962.
10.	Summer, 1963	: WB abandons plans to use Nimbus for operational system; develops TOS concept based on proven technology.
11.	December 21, 1963	: First APT camera launched on TIROS VIII.
12.	January 30, 1964	: Current NASA-DOC management agreement signed.
13.	Spring, 1964	: TOS system design approved as first operational component of NOMSS.
14.	August 28, 1964	: Nimbus I launched. Earth-oriented; improved TV and APT cameras; first High Resolution IR.
15.	January 22, 1965	: TIROS IX launched. First wheel spacecraft. First TIROS in near-polar orbit. First complete global picture coverage daily.

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
WASHINGTON

September 10, 1958

IN REPLY, PLEASE ADDRESS
CHIEF, U. S. WEATHER BUREAU
WASHINGTON 25, D. C.
AND REFER TO

R-3

MEMORANDUM

To : Those Listed Below

From : Director of Meteorological Research

Subject: Satellite Meteorology

The Weather Bureau is about to enter the Space Age. We have been informed verbally by the new National Aeronautics and Space Agency, which NACA will become on 1 October, that the Weather Bureau will be designated as their meteorological agent in providing the meteorological instrumentation, data reduction and analysis of observations taken by satellites after the IGY series is finished.

This decision implies that the NASA has full confidence in the Weather Bureau's ability to carry on this task. A few days ago when key NASA personnel visited Suitland, they appeared to be impressed by our capability in data processing and analysis.

In order to establish immediately a nucleus of competent personnel to carry on this task in all areas it may be necessary to draw on the assistance of present Weather Bureau personnel. As a first step in seeing how this might be done I am calling a conference at the Weather Bureau Conference Room at 10:00 am, Tuesday, September 16, to which you are invited. As a case history in what is required technologically we will examine in detail one of the particular experiments proposed, namely, the satellite TV cloud study experiment.

Harry Wexler

Harry Wexler

Chief of Bureau	W. R. Thickstun	N. B. Foster
R. C. Grubb	G. P. Cressman	V. D. Rockney
L. E. Brotzman	J. Namias	W. F. Staats
T. P. Gleiter	S. Fritz	C. A. Kettering
N. A. Lieurance	D. S. Johnson	F. G. Shuman
F. White		J. S. Winston
R. C. Schmidt		J. K. Angell
		L. F. Hubert
		I. Enger

cc: R. H. Simpson

Attachment

SATELLITE METEOROLOGY

Satellite technology is advancing very rapidly. Extensive meteorological data from satellites are expected within the year. The Weather Bureau must actively enter this field to discharge its responsibilities. A detailed program to this end is now being prepared.

Types of data which are expected in the near future are:

1. Cloud cover data (photocell and T.V.)
2. Heat budget of the earth
3. Nocturnal cloud cover using infrared atmospheric water vapor "window"
4. "Temperatures" as inferred from water vapor and CO_2 emission in the infrared.
5. Ozone distribution
6. Spectrum of solar radiation

Below we have outlined in some detail the steps required in utilizing data to be obtained from one of these experiments - the T.V. cloud cover experiment. It will be evident that a great deal of work is required immediately in the fields of instrument interpretation, data processing, handling and storage as well as meteorological analysis. Considering all other experiments also planned for the immediate future, it is even more obvious that work must begin now in order to handle the vast amount of data soon to be forthcoming.

T. V. CLOUD-COVER EXPERIMENT
(outline of R&D work required)

R.C.A. now has a contract from Dept. of Defense to construct the satellite instrumentation and ground equipment for T.V. observations of the Earth. Many problems are involved in utilizing the data thus obtained. The following ~~outline~~ presents briefly the various steps leading to the final utilization of these data in meteorology.

I. Satellite measurement and initial ground recording. - In order to interpret the data, it is necessary to fully understand and express quantitatively all the links in the measurement process from viewing lens to the recording of the satellite signals at the ground stations. The following are the major links.

   A. Characteristics of the satellite system.

      1. Spectral response - For example, the haze in the atmosphere will reflect more solar energy at some wavelengths than at others. The spectral response will determine whether clouds will be discernible against their background. The spectral response may also be important in determining albedo.

2. Transfer characteristic, i.e. relation between received light intensity and recorded signal on the satellite-borne tape recorder. This is necessary in identifying cloud type.

3. System resolution - determines the amount of cloud detail which can be seen.

4. System stability, e.g., stability of timing in recording and playback process. This is important in positioning T.V. pictures in space. Response stability is important in reducing electronic signals to usable form.

B. Communications link between the satellite and ground stations.

1. Band width - effects resolution.

2. Transfer characteristic - see A2 above.

3. Effect of external interference - Any unwanted signals will interfere with the useful data. Steps must be taken to minimize interference and to account for that which is recorded.

C. Data readout (on film and magnetic tape) -

1. Transfer characteristic - see A2 above.

2. Distortion of signal, e.g., the effect of recording system on resolution and picture "shape".

II. Data Reduction. - The data recorded at the ground stations must be changed into a form suitable for use by the meteorologists. This process involves many steps, such as corrections for instrument characteristics, distortion, interference, etc., correlating with orbital data, conversion to usable form, and data storage.

A. Orbital information - Necessary to position the pictures on the Earth's surface and correct for geometrical distortions.

B. Data requirements of analysis group - Work with meteorologists to determine their requirements. The data reduction program is then planned to present the information in the forms they require.

C. Combine recorded satellite data and orbital information.

1. Remove geometric distortions from T.V. cloud pictures.

2. Position T.V. cloud pictures in time and space.

D. Data Interpretation.

1. Interpret light intensity information, e.g., take account of angular relations between solar beam, optic axis of camera, and reflecting surfaces to determine cloud amount and type.

E. Forms of Data Presentation - Examples -

1. Maps of cloud amount and type

2. Data handling and storage

a. Electronics, film, cards, etc.

III. Meteorological Analysis - In the previous steps, the satellite data have been placed in a form suitable for research and application by the meteorologist. Some of the research projects and applications are outlined below.

A. Application to Analysis and Forecasting.

1. Plot amount and type of clouds on weather maps to help map analysis, storm detection and tracking.

2. Design new methods for using satellite cloud data to improve map analysis.

B. Basic Research

1. Synoptic Meteorology

a. Study of genesis and motion and dissipation of hurricanes and other storms.

b. Study of clouds to determine wind velocity and shear.

c. Determination of atmospheric stability from cloud forms.

d. Development of synoptic techniques for various types of silent areas, e.g., tropics, polar regions.

2. Physical meteorology, e.g., albedo studies of clouds. This is also important in relation to the heat budget studies.

Much work needs to be done before the actual TV satellite data are available. The nature of the signals to be obtained from the ground stations can be determined by engineering studies with RCA. This requires close contact with RCA and their subcontractors.

The complete data acquisition reduction handling and storage system must be designed and equipment obtained before satellite launching. It is anticipated that about 100,000 T.V. pictures will be obtained during the first five months of satellite flight. It is essential that a system be ready to process this vast amount of information in time to aid weather analysis and forecasting.

To prepare for the interpretation of data, analysts must develop preliminary methods of utilizing satellite cloud information. This would include synthesizing cloud information of the type likely to be obtained from the satellite and using this in preliminary analysis and familiarization programs.

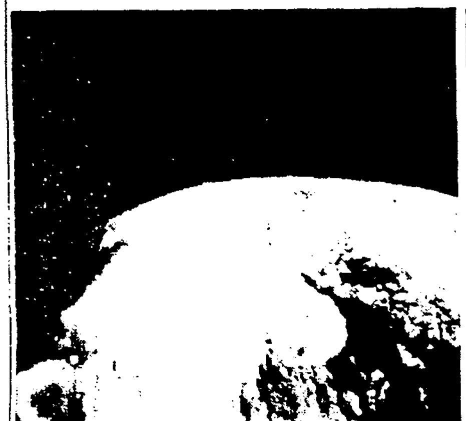
New York Times.

CITY EDITION

U. S. Weather Bureau Report (Page 36) forecasts: Chance of rain today. Windy, mild, chance of showers tomorrow. Temp. range: 56—45; yesterday: 63.6—45.5.

NEW YORK, SATURDAY, APRIL 2, 1960. | 10 cents beyond 50-mile zone from New York City except on Long Island. Higher in air delivery cities. | M | FIVE CENTS

U.S. ORBITS WEATHER SATELLITE; IT TELEVISES EARTH AND CLOUDS; NEW ERA IN METEOROLOGY SEEN



Associated Press Wirephoto

SENT BY SATELLITE: One of TV pictures from Tiros I

The New York Times

CLOUDS: White mass is cloud cover on U. S. and Canada

2 CAMERAS USED

270-Pound Vehicle to Transmit Pictures for 3 Months

By RICHARD WITKIN
Special to The New York Times.

CAPE CANAVERAL, Fla., April 1—The first artificial satellite able to provide detailed photographs of the earth's weather was fired into orbit here today by the United States.

Two television cameras looking down from an altitude of about 450 miles made initial pictures of the earth's cloud patterns during the satellite's second orbital trip.

Four pictures, taken by the wider-viewing and therefore less-precise camera of the two, were proudly distributed this evening by the National Aeronautics and Space Administration. The space agency has over-all responsibility for the project.

The pictures showed the cloud cover that lay over the Northeast United States and the adjacent area of Canada this morning. They also showed an identifiable outline of the gulf of the St. Lawrence River. The curvature of the earth was clearly recognizable.

President Sees Photos

Before being made public, the pictures had been taken to the White House by Dr. T. Keith Glennan, the head of the space

1,014 BILLS LEFT FOR ROCKEFELLER

Albany Weighs Effects of Legislative Session on Prestige of Leaders

Summary of the 1960 session is printed on Page 10.

By WARREN WEAVER Jr.
Special to The New York Times.

ALBANY, April 1—The adjournment of the Legislature early today left conflicting and confused opinions as to who had

AREA: Same places as in TV photos, depicted on a globe

SENATE REJECTS A REFEREE CURB

Quarreling Marks Debate as Kefauver Plan Fails—Courts to Set Hearings

By RUSSELL BAKER
Special to The New York Times.

WASHINGTON, April 1—In an afternoon of angry personal quarreling, the Senate killed the Kefauver amendment to the civil-rights bill today. The vote was 69 to 22.

The amendment, sponsored by Senator Estes Kefauver

R-3.2

JSW/ks Director of Meteorological Research August 30, 1960

David S. Johnson, Chief
Meteorological Satellite Laboratory

PROGRESS REPORT JANUARY 1 - JUNE 30, 1960

I. TIROS I

The successful launch of TIROS I on April 1 was the major event of this period. During its lifetime of about two and one half months TIROS I provided over 20,000 pictures of the earth and its cloud cover with its wide and narrow angle television cameras. In the three months following the launch of TIROS about 50 to 75 percent of the MSS staff was involved in the operational use or research study of TIROS cloud pictures. Several key personnel of MSS were at readout stations at Belmar, New Jersey and Kaena Point, Hawaii during all or part of the operational period. Operational work at MSS in Suitland was concerned with meteorological recommendations for the commanding of the satellite for picture taking; receipt of cloud picture analyses from the two readout stations and their transmission to NMC, Air Force, and Navy; liaison with personnel at the readout stations; and the important problem of determining the satellite's orientation to obtain accurate location of cloud features in the pictures. Much of the staff at Suitland was also concerned with the preparation of prints of pictures and their assembly, along with pertinent standard meteorological data for use in releases of picture data to the press, various scientific groups, and for initial presentation at the spring meetings of the AMS-AGU.

The earliest meteorological results from TIROS were published in two articles, one by Fritz and Wexler in the Monthly Weather Review and the other by Wexler and Fritz in Science. By the end of April a number of case studies of meteorological phenomena observed by TIROS were begun by a team of research meteorologists in MSS. Cases being studied include several large-scale cyclonic vortices over the United States and the North Atlantic and North Pacific; cloudiness in the tropical areas of the South Pacific; cellular arrangements of cumuliform clouds over the Atlantic and Pacific Oceans in temperate latitudes; cloud streets in the Carribbean; cloudiness associated with severe thunderstorms and tornadoes; ice in the Gulf of St. Lawrence; orographic cloudiness in various parts of the world; snow cover in mountain regions; and sun glitter on the ocean surface. Results of these studies will be published this fall in the NASA technical reports series.

II. Personnel Status and Office Space

The following personnel joined the staff of MSS during the first half of 1960:

NAME	FROM	TO UNIT	POSITION
Baliles, Maurice D.	Office of Climatology	Instrument	Met. Technician
Hite, Robert T.	Bureau of Standards	Computation	Statistician
Yamamoto, Giichi	Sendai, Japan	Physical	Meteorologist
Raynore, William R.	Silver Hill Observatory	Instrument	Electronics Technician
Wiens, Rudolph H.	Lehigh University	Physical	Physicist (Summer Trainee)
Hertz, Kenneth J.	University of Pennsylvania	Computation	Mathematician (Summer Trainee)
Springer, Norman W.		Synoptic	Photographic Lab. Technician

Mr. Isaac W. Richardson, meteorologist in the General Circulation Unit, transferred to the National Hurricane Research Project.

With these new additions and transfer the staff of MSS consisted of 40 persons as of June 30.

Final financial arrangements and specifications were drawn up for the new space to be provided for MSS, and contracts for construction were let by GSA before the end of June. Completion of the new quarters is not expected until spring 1961. In view of the anticipated increase in personnel during the summer and early fall, 1960, it will be necessary to arrange for more temporary space with the Air Force at Suitland Hall.

III. Instrumentation and Observation Unit

Technical specifications were prepared for a contract design study of a satellite infrared spectrometer. Twenty five proposals were received and reviewed. A contract has been awarded to Barnes Engineering after discussions with the various scientists advising us on this program.

An investigation has been made of certain possible design approaches to a satellite weather radar. This effort is expected to culminate soon in a report summarizing the desirability of various design approaches for meteorological purposes.

A feasibility study has been completed of a pulsed-light technique as applied to the measurement of cloud top height, dust layers, and ozone from a satellite. A study is also in progress of various possible methods of ozone distribution measurements from a satellite.

Procurement of equipment for an instrument research laboratory has been in progress for some time and some items have already been delivered. A laboratory type infra-red prism-grating spectrophotometer will be delivered in July.

The Instrument Unit is taking part in the system planning for the NIMBUS I satellite, primarily in the basic experiment design and preparations for data utilization.

Supervision and checking of the five Weather Bureau Explorer VII readout stations was continued in this period.

IV. Synoptic Meteorology Unit

Most of the work of this unit in this period was concerned with TIROS I, which is mentioned at the beginning of this report. Aside from participating in TIROS case studies, members of this unit have been concerned with details of logging and filing of TIROS pictures, questions of attitude determination and other documentation of the films, and investigation of ways of best representing nephanalyses in facsimile transmissions. Work prior to launch included the development of a numerical nephanalysis code for transmitting TIROS information via teletype.

Synoptic analysis of the Atlas rocket was completed. In performing this study intensive work was done on analysis of attitude and frame rate.

Pictures from a Boeing 707 cross-country flight obtained from Schaefer were analyzed and preliminary correlations were made with flow patterns.

A summary of the cloud conference of December 1959 was written and coordinated with contributors. This will be issued as a technical report to NASA.

This unit has been working with NASA on plans for photo rocket launches to be conducted later this year at Fort Churchill, Canada.

IV. Computation Unit

Several versions of a latitude-longitude perspective grid overlay code have been produced. These have been used in limited TIROS picture gridding, which has been very important for the case studies of TIROS I pictures, mentioned at the beginning of this report. This overlay code was also useful in generating predicted picture swath information for use in programming the taking of TIROS pictures and in the immediate operational nephanalysis program at the readout stations during TIROS I. Final versions of this code produce latitude and longitude values at 1653 grid points covering the picture image area. This information is placed on tape for further processing by the automatic curve drawing device or alternatively is used in a contour grid point code.

Several codes have also been produced, with the cooperation of NPIC, to furnish photogrammetric feedback for attitude determinations for TIROS I. One code using the horizon and one landmark was available near the launch date, but its use was limited because of picture time uncertainties. A picture code completed in June will produce attitude and time information using several landmarks in a picture.

Flow charting is in progress on the TIROS II radiation data processing. Two sub-routines to be included in this code are 1) the generation of the steradian solid angle intercepted by the earth as a function of satellite height and 2) the generation of solar ephemeris information as a function of time. These sub-routines have both been completed. The analog-to-digital converter has been delivered to GSFC and we have successfully read product tapes of both the IBM 704 and 7090.

The integral equation program for computing radiation intensity has produced a considerable amount of useful output, but line strength information for other parts of the spectrum are needed for more complete output. In order to provide additional infra-red line strength information for the Physical Meteorology Unit, an elaborate sorting and collating program has been devised and is now producing large volumes of information. A revised version of the basic radiation intensity code is being produced in order to fit relative line strength information to certain absolute laboratory measurements.

Coding assistance has been provided to Professor Suomi for use in processing of Explorer VII data. A section of code was completed and sent to him late in the spring.

A new three-part code for production of general circulation parameters has been nearly completed; one part remains in final checkout.

VI. General Circulation Unit

Machine computation of daily northward heat transport has continued throughout this period on a quasi-current basis. These computations, which also include values of the longitudinal contributions to heat transport along each latitude circle, have been analyzed and smoothed in various ways. For latitude 45°N these data have been used to study the heat transport contributions of waves located in various longitudinal zones.

Pending the availability of a code for machine computations of energy parameters, hand calculation of available potential energy has been carried on. Data are now available covering the seasonal buildup of available potential energy from summer into the fall of 1959, through the winter of 1959-60, and the decline in energy into the spring season of 1960. Major increases of eddy available potential energy and eddy kinetic energy generally occur at the expense of zonal available potential energy. The zonal kinetic energy generally does not respond very quickly after a major flux of energy from zonal available energy to the eddy forms. Major changes in each of the energy forms will be studied relative to concurrent and subsequent changes in the other forms of energy and to heat transports to shed more light on the behavior of the atmospheric energy cycle. Further study of a pronounced energy cycle at the beginning of 1959 has demonstrated how the events in one quadrant of the Northern Hemisphere (North America) dominated the changes in the whole hemisphere. Some estimates of generation of available potential energy based on the heating calculations by Wiin-Nielsen and Brown of JNWP are being made for this case, to see if observed energy changes show a clear-cut response to changes in generation of potential energy.

VII. Physical Meteorology Unit

With the aid of the program developed by the Computation Unit, outgoing radiation for portions of the 15 micron CO_2 band and several portions of the H_2O rotation band have been computed. The results have been used in studying the feasibility of using a satellite spectrometer to measure stratospheric temperatures, and in preliminary studies of water vapor emission.

An extended table of absorption by an Elsasser band has been prepared. Also a complete set of spectroscopic data for two water vapor bands was prepared with the aid of a computer code prepared in the Computation Unit.

An initial study of reflection of sunlight from sea surfaces, giving angular dependence and variations with wind velocity, has been completed.

VIII. Papers Published by Members of the MSS

1. Fritz, S. and H. Wexler, "Cloud Pictures from Satellite TIROS I", Monthly Weather Review, Vol. 88, No. 3, pp 79-87, March 1960.

2. Hubert, L. F., S. Fritz and H. Wexler, "Pictures of the Earth from High Altitudes and Their Meteorological Significance", Proc. COSPAR Space Symposium, January 1960.

3. Johnson, D. S., "Image Sensing as Applied to Meteorological Satellites", Journal of the SMPTE, Vol. 69, pp. 14-18, January 1960.

4. Wark, D. Q., "Doppler Widths of the Atomic Oxygen Lines in the Airglow", Astrophysical Journal, Vol. 131, pp. 491-501, March 1960.

5. Wark, D. Q. and R. W. Popham, "TIROS I Observations of Ice in the Gulf of St. Lawrence", _Monthly Weather Review_, Vol. 88, No. 5, pp. 182-186, May 1960.

6. Wexler, H. and S. Fritz, "TIROS Reveals Cloud Formations", _Science_, Vol. 131, No. 3415, pp. 1708-1710, June 10, 1960.

IX. Talks Presented by Members of MSS

1. Fritz, S., "Meteorological Uses of Satellites", Institute of Aeronautical Sciences Meeting, New York, January, 1960.

2. Fritz, S., "Some Meteorological Results Revealed by TIROS I", American Meteorological Society National Meeting, Washington, D. C., April 27-30, 1960.

3. Fritz, S., "Meteorological Satellites", UCLA, Department of Meteorology, May 1960.

4. Fritz, S., "Some Results Sought from Meteorological Satellite Systems", American Rocket Society in Los Angeles, May 1960.

5. Hubert L. F., "Utilization of High-Altitude Cloud Photography", American Meteorological Society National Meeting, Washington, D. C., April 27-30, 1960.

6. Hubert, L. F., "Preliminary Results of TIROS I", Connecticut Valley Branch, American Meteorological Society, Hartford, Connecticut, May 1960.

7. Hubert, L. F., "Meteorological Satellite TIROS I and Examples of Some Early Pictures", OSTIV Technical Meetings, Cologne, Germany, June 1960.

8. Johnson, D. S., "Meteorological Satellites", Geophysical Society of Hawaii and Hawaiian Academy of Science, May 1960.

9. Wark, D. Q., "The Calculation of Outgoing Radiation from the Atmosphere", American Meteorological Society National Meeting, Washington, D. C., April 27-30, 1960.

10. Winston, J. S. and A. F. Krueger, "Some Aspects of a Cycle of Available Potential Energy", American Meteorological Society National Meeting, Washington, D. C., April 27-30, 1960.

David S. Johnson

FORM CD-121 (P-22-62)
(PRES. BY A.O. 206-10)
UNITED STATES GOVERNMENT

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU

Memorandum

S-1

TO : Staff of Meteorological Satellite Activities (MSA)

DATE: June 1, 1962

FROM : S. Fred Singer, Director
Meteorological Satellite Activities

SUBJECT: POLICIES AND ORGANIZATION

Today I am commencing my appointment as Director of MSA. I am pleased and honored by the confidence which the Chief of the U. S. Weather Bureau and the Senior Staff have expressed in me. I am also pleased to be a member of the newest organization in the Bureau which although very young has already established an enviable record. I have already met some of you; I hope to meet all of you individually in the next few days.

It is only right that you should have an idea of how I visualize my job. According to the organization chart, the Director develops objectives, formulates policies and programs to meet these objectives, and sees to it that they are executed. Clearly therefore, we must first of all define our objectives.

The U. S. Weather Bureau has a major statutory responsibility: to provide weather services to the nation. MSA has the responsibility to assist in this mission by using satellites and rockets as an aid to weather prediction.*

This brings us to our central problem. We in MSA in collaboration with other Weather Bureau units must ultimately decide what needs to be observed from satellites and rockets; how to make these observations, how to use them, both now and in the future. This is a job in scientific management for which we have the necessary capabilities. It means combining the basic scientific inputs, which come from universities and private research laboratories, as well as from other government laboratories, with our skill and knowledge in using data in meteorological research and forecasting. It is in recognition of this capability that the Defense Department, NASA, and the FAA have recommended that the Weather Bureau be assigned the responsibility to operate the National Operational Meteorological Satellite System. Congress has affirmed

*On September 30, 1961 the Congress of the United States in Public Law 87-332 appropriated funds to the Weather Bureau "for expenses necessary to establish and operate a system for the continuous observation of worldwide meteorological conditions from space satellites and for the reporting and processing of the data obtained for use in weather forecasting". To handle the new responsibilities of this program as well as the expanding research in meteorological satellites, the Department of Commerce approved the establishment of MSA in January, 1962.

this recommendation by granting funds to the Weather Bureau to set up an organization for this purpose, namely MSA. This means that we are responsible for the funds, and are held accountable for their proper use.

We must recognize at the outset that scientific competence in meteorology and satellite technology is spread all over the United States, and indeed internationally; therefore, our main job will be to work well with these scientific groups. In recognition of this we intend to establish an even closer liaison in the basic research field with universities and similar non-profit institutions, with activities in the Department of Commerce, with NASA, as well as with other government laboratories which are carrying on meteorological or related research. Our job will be to encourage them, assist them when necessary, and in all cases try to induce competent scientists (of whom there are too few) to devote their attention to meteorological problems so that we may ultimately have the benefit of their research results and of their advice.

In other words, we will function as a catalyst and as organizers. We cannot and will not attempt to do all of the important work within MSA, but what is done within MSA will be of the very highest quality. This is assured by the excellent staff scientists we already have; they will be augmented where necessary in order to round out our capabilities. I am particularly hopeful that we can continue to expand the number of visiting appointments for meteorologists and atmospheric scientists who wish to use satellite data and would like to attach themselves for a period of time to MSA.

We will also assist as much as we can in the general Weather Bureau effort to induce universities to expand teaching facilities in atmospheric physics and meteorology so as to ensure a supply of well-trained scientists for the future.

It is to private industry we look for assistance on a wide range of problems, from management consulting to human engineering, from data handling and display, to the construction of special scientific instruments and the analysis of data. There are great opportunities for industry in our area. Our industrial partners who come in with us "on the ground floor" will benefit by educating their own personnel in weather problems and will be in a superior competing position in the future. Even though the initial contracts may be small, we look to industry management to show vision and imagination in working with us and giving us their best efforts.

At this point I would like to define the functions of the Deputy Director and the Assistant Directors of MSA. The Deputy Director, Mr. David S. Johnson, is of course well known to you since he has been Acting Director of MSA since its inception. He and I will share direction in a manner best suited to our interests and talents. In my absence he will assume the duties and responsibilities of the Director.

Dr. S. Fritz, who is Chief of the Meteorological Satellite Laboratory, will also serve as Acting Assistant Director for Research and Systems Planning. He has acquired an international reputation for his scientific work, and in particular in his pioneer work in radiation and in satellite meteorology. I will look principally to him for guidance on how to carry out the major objectives of MSA, namely, of deciding on what to observe, how to do it, and how to use the results.

Mr. Arthur W. Johnson is Assistant Director of Operations and heads the operating arm of MSA. The satellite data, their handling and processing, their display and storage, and their distribution - all of these fall within his domain. These are among the most difficult and challenging problems that face us, but I am sure that we will do them well. It is the feedback that comes from the operational uses of satellite data which will tell us whether we are making the right kinds of observations. We must find these answers as quickly and efficiently as possible.

A new appointment is that of Mr. J. Gordon Vaeth who is joining MSA to become Assistant to the Director for Special Programs and Resources Management. In order to do our job properly we need to be constantly aware of the requirements of our customers. Our main customers are, of course, the American public and the military weather services, but we have many other customers - the Defense Department, the FAA, NASA, all of whom may require special services which relate to the atmosphere. In planning our program, particularly for the future, we must anticipate what these requirements will be. It requires constant liaison, and it requires an active selling job to tell our "customers" what we are able and willing to do for them. On the other hand, we need to be aware also of the capabilities of industry as they relate to our mission. This again requires a focal point within our organization where industry can make their resources known to us and where we can describe our requirements to them.

In conclusion I would like to remind you that we are privileged to work on a program which is perhaps the most exciting and worthwhile one of the many space programs. I firmly believe that the potential improvement in the national economy inherent in improved weather prediction has not nearly been realized and cannot even be imagined at this stage. In addition, weather prediction has a demonstrated significance for our national security.

President Kennedy has just recently pointed to the great international significance of weather satellites. This has been emphasized by recent actions in the United Nations and the World Meteorological Organization. If we do our job well, we will further enhance the stature of the United States in the space field. We are already leading in the use of satellites for meteorology; our determined efforts and hard work will keep us moving in front. I know that not only the people at home but the whole world is watching us to see how well we do. I am sure that we will not let them down.

S.F. Singer

S. Fred Singer

USCOMM-WB-DC

cc: Distribution List A

NESDIS 77 NOAA Polar Satellite Calibration: A System Description. Cecil A. Paris, April 1994.

NESDIS 78 Post-Launch Calibration of the Visible and Near Infrared Channels of the Advanced Very High Resolution Radiometer on NOAA-7,-9, and -11 Spacecraft. C. R. Nagaraja Rao and Jianhua Chen, April 1994.

NESDIS 79 Quality Control and Processing of Historical Oceanographic Nutrient Data. Margarita E. Conkright, Timothy P. Boyer and Sydney Levitus, April 1994.

NESDIS 80 Catalogue of Heavy Rainfall Cases of Six Inches or More Over the Continental U.S. During 1993. Richard Borneman and Charles Kadin, August 1994.

NESDIS 81 Quality Control and Processing of Historical Oceanographic Temperature, Salinity, and Oxygen Data. Timothy Boyer and Sydney Levitus, August 1994.

NESDIS 82 An Introduction to the GOES I-M Imagr and Sounder Instruments and the GVAR Retransmission Format. Raymond Komajda (Mitre Corp), November 1994.

NESDIS 83 Tropical Cyclone Motion Forecasting Using Satellite Water Vapor Imagery. Vernon F. Dvorak and H. Michael Mogil, December 1994.

NESDIS 84 Spurious Semi-Diurnal Variation in the E.R.B.E. Outgoing Longwave Radiation. C. R. Kondragunta and Arnold Gruber, June 1995.

NESDIS 85 Calibration of the Advanced Microwave Sounding Unit-A for NOAA-K. Tsan Mo, June 1995.

NESDIS 86 A Spectral approach to the Forward Problem in GPS Radio Occulation Remote Sensing (Ray Tracing, Assimilation, Tomography). Simon Rosenfeld, July 1996.

NESDIS 87 Proceedings of the International Workshop on Oceanographic Biological and Chemical Data Management. Sponsors Intergovernmental Oceanographic Commission, U.S. National Oceanographic Data Center, European Union MAST Programme, May 1996.

NESDIS 88 Analytical Model of Refraction in a Moist Polytropic Atmosphere for Space and Ground-Based GPS Applications. Simon Rosenfeld, April 1997.

NESDIS 89 A GOES Image Quality Analysis System for the NOAA/NESDIS Satellite Operations Control Center. Donald H. Hillger and Peter J. Celone, December 1997.

NESDIS 90 Automated Satellite-Based Estimates of Precipitation: An Assessment of Accuracy. Michael A. Fortune, June 1998.

NESDIS 91 Aliasing of Satellite Altimeter Data in Exact-Repeat Sampling Mode: Analytic Formulas for the Mid-Point Grid. Chang-Kou Tai, March 1999.

NESDIS 92 Calibration of the Advanced Microwave Sounding Unit-A Radiometers for NOAA-L and NOAA-M. Tsan Mo, May 1999.

NESDIS 93 GOES Imager and Sounder Calibration, Scaling, and Image Quality. Donald W. Hillger, June 1999.

NESDIS 94 MSU Antenna Pattern Data. Tsan Mo, Thomas J. Kleespies, and J. Philip Green, March 2000.

NESDIS 95 Preliminary Findings from the Geostationary Interferometer Observing System Simulation Experiments (OSSE). Bob Aune, Paul Menzel, Jonathan Thom, Gail Bayler, Allen Huang, and Paolo Antonelli, June 2000.

NESDIS 96 Hydrography of the Ross Sea Continental Shelf During the Roaverrs, NBP96-06, Cruise December 1996 - January 1997. Michael L. Van Woert, David Pryor, Eric Quiroz, Richard Slonaker, and William Stone, September 2000.

NESDIS 97 Hydrography of the Ross Sea Continental Shelf During the Roaverrs, NBP97-09, Cruise December 1997 - January 1998. Michael L. Van Woert, Lou Gordon, Jackie Grebmeier, Randal Holmbeck, Thomas Henderson, and William F. Van Woert, September 2000.

NESDIS 98 NOAA-L and NOAA-M AMSU-A Antenna Pattern Corrections. Tsan Mo, August 2000.

NESDIS 99 The Use of Water Vapor for Detecting Environments that Lead to Convectively Produced Heavy Precipitation and Flash Floods. Rod Scofield, Gilberto Vicente, and Mike Hodges, September 2000.

NESDIS 100 The Resolving Power of a Single Exact-Repeat Altimetric Satellite or a Coordinated Constellation of Satellites: The Definitive Answer and Data Compression. Chang-Kou Tai, April 2001.

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following types of publications:

PROFESSIONAL PAPERS - Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS - Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS - Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS - Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS - Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS - Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Washington, D.C. 20233